



Performance measures of the SESAR Southwest functional airspace block[☆]



Cesar A. Nava-Gaxiola^{*}, Cristina Barrado

Universitat Politècnica de Catalunya (UPC), Castelldefels, Spain

ARTICLE INFO

Article history:

Received 11 May 2015

Received in revised form

7 August 2015

Accepted 11 September 2015

Available online 28 September 2015

Keywords:

Functional airspace block

Free route airspace

SESAR

Airspace reconfiguration

ATM performance measurement

ABSTRACT

To face the challenges of the increasing air traffic demand the ICAO proposed the Performance Based Approach (PBA) as the methodology to apply for the modernization of the Air Traffic Management (ATM). Improvements for enhancing the en route air traffic efficiency include more direct route options and flexible airspace structures. In Europe airspace structures are fragmented by State boundaries avoiding cross-border sector configurations. Functional Airspace Blocks (FAB) are operational instruments of SESAR to facilitate the implementation of the Essential Operational Changes. In the Southwest FAB the plan to introduce Free Route Airspace (FRA) across States is the main change foreseen. The Southwest FAB comprises Portuguese and Spanish airspaces and with the FRA there will be no longer discrete crossing points. The relevance of SW FAB is due to its geographical situation, being one of the most important interconnection nodes for the American transatlantic flights and the European northern–southern corridor. In the paper we provide some measures of the expected benefits of introducing the FRA in Southwest FAB. The aim of the measures is to be useful for the performance analysis of the Southwest FAB development and the FRA already started in May 2014.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The liberalization of the European aviation market in 1993 made travel much more accessible and has stimulated growth in air services. Since then, European air traffic has increased by 54%. Air traffic control in Europe was fragmented and inefficient. Comparing the European and American airspace, which are roughly the same size, Europe has 38 en route air navigation service providers (ANSP) and the United States has just one, the Federal Aviation Administration (FAA). In addition FAA manages twice as many flights as Europe with the same costs (Eurocontrol, 2011a) (60,000 flights a day vs. 30,000 in Europe).

Nowadays, European airspace is still structured around national boundaries, thus flights are scarcely able to take direct routes which would save fuel, costs and be more environmental friendly. The estimated cost of airspace fragmentation in Europe amounts to 4 billion EUR a year (European Commission). The Single European Sky (SES) political initiative establishes cross-border blocks of airspace as part of the programme for the modernization of the

European air traffic control and airspace management. The Single European Sky ATM Research (SESAR) is the operational and technological element for the SES. SESAR aims at developing the new generation of the European ATM system capable of ensure safety and fluidity of the air transport with a uniform high level of interoperability and efficiency for the next several decades (Skybrary).

One of the key elements of the SES is the introduction of Functional Airspace Blocks (FAB). With FAB routes and airspace structures are no longer defined in accordance with national borders but in accordance with the operational traffic needs. The air navigation services and related functions are optimized through enhanced cooperation between ANSP, reducing navigation cost. On the other side, FAB are expected to increase capacity and flight efficiency for airspace users. According to the future SES program, the current reorganization of the 67 airspace blocks in Europe (all based on national boundaries) are going to be reorganized into only nine functional airspace blocks (Eurocontrol).

The Southwest (SW) FAB comprises Portuguese and Spanish airspaces. The importance of the SW FAB is related with its geographical situation, because this airspace is a natural gateway to Central and South America flights. The airspace of the SW FAB plays an important role in the European and international air transport

[☆] This work has been founded by the Ministry of Spain under research contract TRA2013-45119-R.

^{*} Corresponding author.

being the main link between Europe and a community of more than 400 million inhabitants with increasing travelling requirements (Southwest FAB). Six thousands flights a day cross this airspace and the type of traffic makes it ideal for implementing Free Route Airspace (FRA). In harmony with FAB principle (no national border constraints) the process to set up FRA in the future SW FAB is divided in three phases, starting from the integration of some Portuguese and Spanish sectors (Lisbon, Santiago and Asturias), and enlarging the FRA to Santa Maria Oceanic and Canarian airspace in successive phases. The FAB implementation is based on traffic flows, airspace capacity analysis, safety and human factors evaluation. A set of entry/exit points in the FRA boundaries define the letters of agreements and coordination process, being the flight inside the FRA direct routes.

Determining FAB improvements has been challenging for the ATM research community because it needs an approach from different viewpoints for quantifying benefits for stakeholders (commercial airlines, ANSP, industry, National authorities military, staff associations, etc.) This paper evaluates different airspace scenarios simulating the future SW FAB phases (PSDCA, 2012), and provides performance measures in terms of flight efficiency and controller taskload. These are the most important metrics of interest to airlines and ANSP.

The paper organization is as follows: Section 2, summarizes the background and previous researches. Then, Section 3 presents the metrics that are evaluated in the paper. The simulation processing is explained in Section 4. The next part (Section 5) exposes in detail the scenarios modeled. Follows Section 6 with the presentation of the obtained results. Finally, paper conclusions are exposed in Section 7.

2. Background

The origin of the FAB concept development across Europe started with the Maastricht Upper Area Control Centre (MUAC). MUAC provides air traffic control for the upper airspace (flight level above 24,500 ft or FL245+) of Belgium, the Netherlands, Luxembourg and the North-West of Germany. Consequently, this airspace has proven the FAB concept by showing the advantages of this kind of international cooperation (Eurocontrol, 2011b).

The first study that introduced the FAB concept in the current SES regulation was conducted by authors in (Wilmer et al., 2001). They proposed to join the upper airspace management of some areas from the national ANSP to new created FAB. The regulatory framework on which FAB were developed was settled in the first legislative package of the Single European Sky (SES I). Nowadays FAB is the main mean for reducing the European airspace fragmentation. The SES II tackles the creation of FAB in terms of service provision, in addition to the airspace organization issues (SW FAB, 2012a).

In addition to the regulatory framework, a pure economic study (Baumgartner and Finger, 2014) shows how the SES has many stakeholders (airliners, ANSPs, industries, government agencies, etc.) with different objectives, some of them divergent and arguments that the main stakeholder with clear goals and potential benefits in FAB implantation are the commercial airlines. Another economic study of the European FABs (Button and Neiva, 2013) concludes that the fragmented air traffic management in Europe impacts on safety, limits airspace capacity, and above all, adds costs to the system.

The Southwest FAB is a part of the nine FAB program in Europe. The FAB implementations are long term plans and have been suffering important delays. The BLUE MED FAB has not been formally established yet and the Commission has started infringement procedures for four of the nine FAB for the slow

reorganization process. A map of these programs can be appreciated in Fig. 1.

The Portugal–Spain FAB aims at fulfilling the SES requirements by enabling the expected traffic growth, reducing environmental impact, continuously improving safety and enhancing cost efficiency. Besides, SW Portugal–Spain FAB has been defined in accordance with the stakeholder's expectation. As a result, an Operational Plan (PSDCA, 2012; SW FAB, 2012a; SW FAB, 2012b; SW FAB, 2015) was developed and maintained in order to bring the guidelines in the airspace changes.

The SW FAB Operational Plan includes a number of projects related with network improvements, new cross border configuration between Spain and Portugal, reorganization of parallel routes between Iberian Peninsula and Canary Island that use Morocco airspace, etc. The most important one is the FRA implementation, which will permit to create the largest free route area in Europe (Southwest FAB).

The implementation of the free route airspace in Europe is an operational enabler of SESAR and its activation is encouraged by the regulation where feasible (EU No 677/2011). Although not mandatory, the SW FAB decided to adopt FRA in order to straighten the FAB air routes and to obtain the consequent reduction in the total flown distance.

The Operational Plan defines three FRA phases: Phase I (Lisbon and FRASAI airspace), planned from 2009 to 2014, will complete in 2015. The next phases (Phase II and III) include Santa Maria Oceanic Airspace and Canary Islands airspace. Those phases will be initiated successively after completion of phase I and are part of the long term SW FAB airspace projects for 2020 (SW FAB, 2012a).

The adaptation from aircraft operators to the new airspace organization depends only on them. If they want to fly in FRA area, they must plan routes by the FRA rules. In general, operators will be satisfied to adapt to this change because for them FRA is the way to save money (Kraus, 2011). The potential of the extension of the free route concept in the SW FAB is promoted by NAV and ENAIRE, the Portuguese and the Spanish ANSP respectively.

The ICAO has decided to use the Performance Based Approach (PBA) as the methodology to follow to face the challenges of increasing air traffic demand. The ICAO Manual on Global Performance of the Air Navigation System (ICAO, 2008) defines PBA as “a decision making method, based on three principles: strong focus on desired/required results, informed decision making driven by those desired/required results, and reliance on facts and data for decision making”. Following this approach, in its Master Plan the SESAR

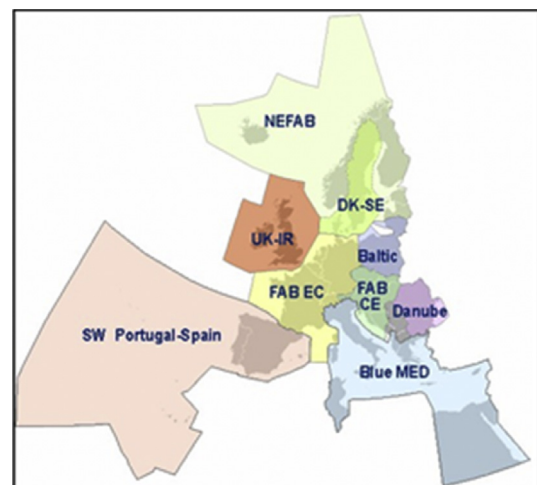


Fig. 1. European FAB programme (source in (Skybrary image)).

programme identifies the “need for a single, simplified European ATM System coupled with a performance-based approach that will satisfy all stakeholders’ requirements”. Two important items can be extracted from these two documents: First the need to rely on data to make decisions and to follow results, and second the importance of defining metrics for all involved stakeholders. In fact, EUROCONTROL evaluations mention that FAB establishment between State members will need to be supported and justified by its overall added value based on cost-benefit analyses, considering that operational advantages are linked to all stakeholders (Eurocontrol, 2005). A long list of previous work exists presenting measures of the ATM system: For instance, Yifei et al. (2011) propose new methods to assess the complexity of the air traffic other than the traditional taskload metric derived from the rate between traffic demand and capacity. Airways geometry and a complex collision risk model are combined in a non-linear function to obtain colored maps that show the complexity levels at different spots of the airspace. Idris and Shen (2013) estimate of the capacity of a sector from a risk mitigation metric. They named adaptability to the number of feasible trajectories available to an aircraft that avoid traffic constraints. The arrival traffic of two sectors of the Chicago O’Hare airport was used for analysis using two different control strategies in a metering situation: a human path stretch strategy and an alternative automated one. The paper showed the relation between adaptability and capacity, but also the influence of the level of automation of the controllers’ tasks in the estimation.

Other previous works provide data evidences for some new Next Generation Air Transportation System (NextGen)/SESAR concept or technology. For instance, the introduction of new operational procedures at the tactical level has been assess in Knorr et al. (2011), Ryerson et al. (2011), McNally et al. (2013), and Gaydos et al. (2013): The impact of cruise-speed reduction to absorb delays is evaluated in Knorr et al. (2011) using metrics of fuel consumption. The same metrics are used to assess other three operational performance measures (schedule aircraft, airborne delay and departure delay) in Ryerson et al. (2011). Dynamic weather routes is a promising system that searches and proposes changes on the cruise route depending on the weather situations (threads, winds ...) (McNally et al., 2013) had analyzed the flights of a commercial company during a 3-month period proposing route changes through an automated system. The metrics used were flight minutes saved, and the impact of rerouting in the sector congestion. Gaydos et al. (2013) measure the increase of the number of medium-term conflict resolution advisories produced by trajectory-based descends. Traffic on Denver International Airport, evaluated 90 min long, involved 80 aircraft, 36 of them in descend and the rest as en-route. An average of one false alarm every 2.5–3 min show that the current tools are not acceptable for dealing with trajectory-based descends. Related to FAB measures, (Mihetec et al., 2012) indicates that the number of operational concepts currently put in place in the FAB implementation makes it difficult to meet the objective of a win–win situation for the individual stakeholders.

Pozzi et al. (2011) focus on the evaluation of safety as a way to highlight the gap that exists when trying to transform large amount of real-time data into operationally relevant recommendations. The authors combine big-data processing systems with operational expertise to detect loss of separation and predict dynamics of disturbance propagation. The safety data processing system is evaluated using real-time radar data at the Italian ANSP (ENAV) experimental centre. The paper focus on the necessity of involve experts to identify patterns after the quantitative big-data processing. The aircraft synchronization concept (Zanin, 2013) is also a metric proposed to measure the safety of airspace given a list of aircraft trajectories. This metric accounts for aircraft that have some

degree of dependent behavior and shows to be a good indicator of the loss of separation situations, especially by some previous route deviation action.

A long list of works develop matrices for measuring workload/taskload of the controllers, especially of interest for ANSP and capacity calculation. Welch et al. (2013) propose a full workload model to be used by an ANSP in deciding sector capacity in case of weather events. The model applies regression on an extensive list of metrics related to ANSP: aircraft count, peaks of traffic, throughput (aircraft per hour), weather, task recurrences, mean transit time, size of the sector volume. The model shows to predict capacity more accurately in all weather conditions. Based on their contribution to total variance of a regression analysis (Vogel et al., 2013) selects 19 complexity metrics and combines them in 6 aggregated super-factors to predict the controller workload and collision risk using dynamic density themes. The introduction of the human models in the complexity factors observed significant correlation between traffic complexity and workload when evaluated in a fast-time simulation. In contrast the authors were not able to find any significant correlation between the workload and the level of safety, even when modeling the effects of temporal delays in human activities. In Timar et al. (2013) a benefit analysis is presented to assess the Performance Based Navigation (PBN) applied in Standard Terminal Arrival (STAR) procedures with shared fixes. A queue model is proposed for the Northern California Metroplex. Results show the traffic distribution, the airspace utilization and the throughput (as percent of the capacity) for several routing alternatives and RNAV performances. All these metrics are given from the point of view of the ANSP but not for any other stakeholder.

Zou et al. (2013) cover the point of interest of the airspace user and presents metrics of flight efficiency. The authors define flight inefficiency in terms of fuel consumption using three alternative approaches: ratio-based, deterministic and stochastic. Ratio-based indices relate a unit of burned fuel with some output metrics such as distance, passengers or economic benefits. The deterministic frontier model uses a linear function to model fuel consumption. The stochastic frontier model introduces a new term in the previous linear formula to model idiosyncratic errors. The new term is stochastic and follows a half-normal distribution. Analysis was done for 15 airlines accounting the 80% of the fuel consumption in U.S. domestic airspace. The resulting ranking of companies flight inefficiency, derived from each of the metrics, show not strong differences, with average fuel inefficiencies of 9–20%.

At the strategic level (Wojcik et al., 2013), presents metrics to measure the flexibility provided by a departure queue management system based on collaborative decision making (CDM). The authors use fast time simulations of aircraft departures and show a number of delay-related metrics to compare inter-airline exchanges vs. intra-airline exchanges only. Also (Vaze and Barnhart, 2011) evaluates different slot allocation schemes and provides results using delay-related metrics, but also airline operating profits, and passengers-related indicators. Strategic planning is proposed in Tobaruela et al. (2013) to improve cost-efficiency in case of capacity reduction. Delay metric is given as a ratio of minutes between different capacities studied.

In a similar approach to ours (Lee et al., 2011) evaluates the benefits and feasibility of the Flexible Airspace Management concept (FAM) from different perspectives. FAM concept is part of the NextGen implementation plan which allows dynamic reconfiguration of the airspace structure. In particular, they modify sector boundaries in order to balance air traffic peak demands over capacity. The evaluation is done through simulation and takes into account the efficiency interests of the airlines (flight distance and time), the controllers’ taskload (number of reroutings, aircraft counts) and safety issues (bad weather penetrations, separation

violations). Since the simulations have human-in-the-loop, also subjective useful information is obtained about the roles, procedures and tools.

3. Metrics evaluated in the Southwest functional airspace block

The approach to metrics evaluation is present in the SESAR feasibility reports for future FAB. Those reports take into account safety issues, capacity evaluation, cost-effectiveness, flight efficiency, environmental issues, military mission and controller productivity (PSDCA, 2012; Eurocontrol, 2011b; ANA de Luxembourg, 2008). In line with these feasibility reports, this research produces metrics grouped in two main guidelines: airspace users and ANSP.

From airspace user perspective (commercial aircraft operators), the most important goal is to complete a safe operation with the highest benefit. This is traduced in flying the cheapest route, which in the absence of significant weather conditionings, especially winds, or high differences in the airspace taxes, corresponds to the shortest or most direct route available for the operation. As a result engine fuel burn is reduced, flight time saved, pollution reduced, etc. For all these reasons, flight distance is the airspace users' metric proposed to evaluate the FRA flight trajectories.

On the other hand, this paper studies the ANSP situation with the future Southwest FAB. This work proposes the taskload of the controllers as the ANSP main indicator. In addition the potential aircraft separation losses are evaluated. All this to bring a complete overview of how conflicted will turn the airspace for ATC controllers with SW FAB implementation.

The method to calculate ATC taskload follows a CAPAN-like process (Eurocontrol, 2013–2014), accounting for a set of basic controllers' tasks for each flight crossing one sector, according to the flight profiles, the critical flight events and the conflicts detected.

Each controllers' task has a position responsible (executive, planner controllers or both) and an execution time. Two metrics are shown: the total taskload and the peak taskload per hour. While the first taskload measures the volume of work in minutes in a whole day, the second, measured in percentage, provides better understanding of the traffic coincidence in time.

The number of potential separation losses of the traffic is measured taking into account a volume around the aircraft with a threshold of 1000 ft in vertical and 10 NM for horizontal separations.

The calculations of the SW FAB metrics are done using the NEST (Network Strategy Tool) software from EUROCONTROL. NEST is similar to most modelling tools; the user creates scenarios to then run analysis routines to generate series indicators and measurements (Eurocontrol, 2013–2014).

4. Simulation process

The process for the traffic simulation which includes three main stages: A first stage to define the SW FAB scenario to be evaluated, given by the airspace specific configuration, the navigation points, flight levels and sectors of scenario selected dates. The first stage also includes the extraction of the actual air traffic crossing such airspace. The second stage is devoted to the data processing and sampling utilizing the NEST functions and external support tools. The final stage consists in obtaining the metrics values as defined in Section 3. Fig. 2 brings a general overview of the three main stages of the simulation process.

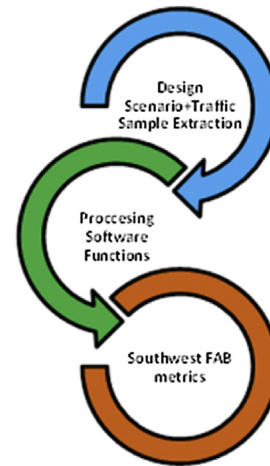


Fig. 2. Simulation processing stages.

4.1. Definition of the baseline scenarios

This paper defines two baseline scenarios, the ACTUAL and the FUTURE scenarios, with two different sets of traffic samples: The ACTUAL scenario is extracted from the EUROCONTROL historical air traffic Data Demand Repository (DDR2) database for years 2013–2014, before the FRA was established in Spain. The FUTURE scenario provides a traffic forecast for 2019. The reason of presenting two scenarios is to obtain measures both in the short term (more realistic and accurate) and in the long term (best suited for the SW FAB long term implementation).

The 24 h flight trajectories of the air traffic of 5 days are extracted from the DDR2 database. The selected days are from different AIRAC cycles, and the traffic traces contain only the segments inside the SW FAB. The selection criterion was to consider normal operational days of different seasons and not affected by adverse weather phenomena, strikes, holidays, or any other external perturbation. One of the 5 days has a slightly higher traffic density; this is linked to a summer Saturday.

For the FUTURE scenario, a traffic forecast to 2019 was performed using NEST and from the traffic samples of the ACTUAL scenario. The traffic forecast method (Eurocontrol, 2013–2014) considers a medium-term forecast that combines the flight statistics with the economic growth and with the models of other important drivers in the industry, such as costs, airport capacity, passengers, load factors, aircraft size, etc. The traffic increment for the 2019 forecast resulted in an average increment of 15%.

Table 1 presents the air traffic samples dates and number of flights for both scenarios:

For both baseline scenarios we use the same airspace and sector configurations. The vertical limits of the FAB sectors are defined according to the SW FAB plan: from FL245 to FL660. The opening scheme or configuration of sectors during the day is considered to be fixed, with 14 sectors. This configuration is decided according to the actual airspace configuration of the Day 1. The 14 sectors configuration is the configuration used for the longest period during the day/busy time.

5. Southwest functional airspace block scenarios

The scenarios modeled in the NEST tool follow the Operational Plan phases of the SW FAB, based on the implementation details and calendar given in Section 2.

In the design of the scenarios, the navigation waypoints

Table 1
Traffic Samples

Sample	Day 1	Day 2 (highest)	Day 3	Day 4 (lowest)	Day 5
Dates of ACTUAL	Sat 04/13/13	Sat 08/17/13	Wed 11/13/13	Tue 01/21/14	Thu 04/03/14
#Flights ACTUAL	1423	1901	1371	1221	1629
Dates of FUTURE	Sat 04/13/19	Sat 08/17/19	Wed 11/13/19	Mon 01/21/19	Wed 04/03/19
#Flights FUTURE	1618	2177	1510	1423	1994

maintain their current coordinates, as in the baseline scenario, but their significance changes according to the configuration label. Fixes can be defined as entry, exit or intermediate points, as established in the SW FAB plan. For instance, the fix DETOX (located in Lisbon FIR) is an entry/exit point in Phase I, but in Phase III this fix becomes an intermediate point, because this fix is no more in the FRA limits. The flight level limit of all the Phases is from FL245 to FL660.

5.1. Phase I Southwest FAB

The first phase evaluated in this paper includes the airspace related to Lisbon FIR (Portuguese) and the FRASAI (Spanish). In contrast to the current situation both airspaces are joined in a unique air block with free route configuration, while the surrounded sectors of the SW FAB are still operating in non-FRA way.

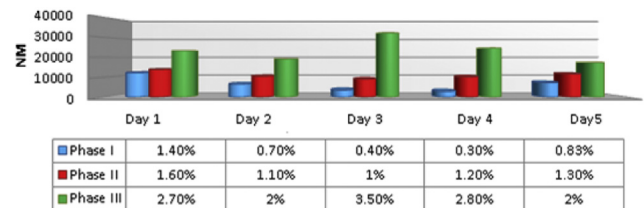
5.2. Phase II Southwest FAB

The second phase of FRA project is based in the extension to Santa Maria Oceanic FIR. The most interesting point, as was defined before, is the possibility to offers flights without restrictions (direct routes), so at the end of this phase, will be possible to offer flights from the exit point of a Madrid SID (Standard Instrument Departure) to New York Oceanic FIR, at 40 W.

5.3. Phase III Southwest FAB

The final phase includes the implementation of Free Route Airspace extended to the Canary Islands FIR. This extension represents a big change in the SAT (South Atlantic Corridor), due to the significant traffic demand increase. Phase III will be a natural gateway to Central and South America, as a plays an important role in the European and international air transport being the main link between Europe and a South America community (Southwest FAB, 2015).

Fig. 3 shows in different colors the three phases, each one containing the previous and extending to the new colored area.

**Fig. 3.** Southwest FAB phases plotted with the main airspace segments.**Distance Saved (NM) for each Free Route Phase Implemented****Fig. 4.** Flight distance differences of the 3 phases for the ACTUAL scenario.

6. Results

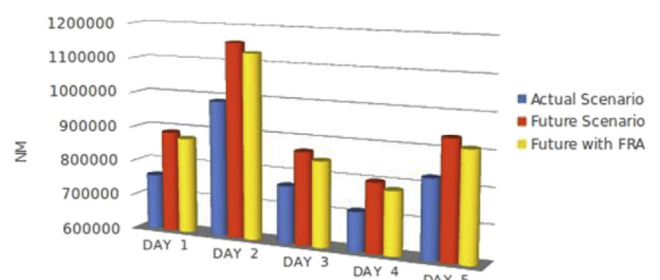
This section shows the metrics results for the ACTUAL and the FUTURE traffic benchmarks. We applied the ACTUAL traffic to the three implementation Phases of the Operational Plan of the SW FAB. For the FUTURE scenario only the third Phase is modeled. For all scenarios the metrics presented are the flight distance, the taskload (average and peak) and the number of potential separation losses.

6.1. Flight distance

Using the ACTUAL traffic samples of the 5 days of 2013/14 and the actual airspace configuration the flight distance metrics can be observed in the blue plot of Fig. 5. As expected the Day 2 which had the highest number of flights is also the one with highest flight distance value (987,482 NM). The day with the lowest value (712,746 NM) is Day 4. To better understand this flight distance values, we provide the fuel consumption and CO₂ emissions corresponding to it by using the relation equation exposed in the AIRE programme (SW FAB, 2015):

$$1\text{NM} \equiv 10.44 \text{ fuel kg} \equiv 3.15 \text{ CO}_2 \text{ kg} \quad (1)$$

And using the fuel ton price of 540 €, according to IATA fuel monitor (April, 2015), then the flight fuel cost from 4 to 5.5 million € per day and produces about 2–3 thousand tons of CO₂ only in the

Distance (NM) for FUTURE scenario**Fig. 5.** Flight distances of the ACTUAL and FUTURE scenarios.

SW FAB.

Fig. 4 shows the flight distance reductions obtained for this same traffic if applying the 3 Phases of the Operational Plan. As a first observation, we see that benefits already start with the application of the Phase I free route. Although the area of Phase I is not very extend, the number of flights of this continental area is relatively dense and free route has an impact. Same happens with Phase II. But it is with the implementation of Phase III where we obtain the best metrics values, with savings of 190 tons of fuel, 57 tons of CO₂ emissions per day, and an overall reduction of costs of 100,000 € each day in mean. It can be summarized in a saved distance up of 2.25% for all flights.

For the FUTURE traffic benchmark the flight distance metrics can be seen in Fig. 5 together with the ACTUAL values for a better contrasts. Observe that the tendency of the 5 days is very similar. Comparing the ACTUAL with the FUTURE scenarios, the overall flight distance has an increase of the 15% and a mean of 121,400 NM more per day. Again the result of applying free route to these traffic has a benefit in all days now of a 2.3% in mean.

The presented airspace users' metrics results give back some evidence of this existing connection between direct routes a distance saved. They demonstrate the attractive benefits of the SW FAB free route airspace for the airlines, presenting advantages like less fuel consumption, environmental friendly flights or flight time saves.

6.2. Controllers' taskload

The results of controllers' taskload (volume and peak) of the ACTUAL scenario are exposed in Fig. 6, for the executive controller and planner controllers. The controllers' taskload volume provides an objective measure of the total estimated minutes devoted to controlling tasks during one day (24 h). It gives a measure of the

quantity of work in a sector. On the other hand the taskload peak gives a better view of the distribution of such tasks across the day by accounting the maximum peaks of work in intervals of 15 min. Taskload peaks are given in percent of peaks of work per hour. Both taskload metrics are separately shown per sector, using opening scheme with the following 14 sectors. In the taskload peak figures the location of the most relevant sectors is shown. Table 2.

As a first observation we have to put the taskload volume values in context: the maximum taskload is 351.48 min (Sector 12, Day 2) and means that a person working 24 h will be busy 'only' the 24.4% of its time. In fact, during the less-busy hours, sectors are grouped together and are under the supervision of one executive and one planner controllers, thus individual taskload are in fact higher when the configuration has less than 14 sectors. We should look at the taskload measures just as a quantification of the volume of work, and do not directly relate them with sector capacity or the overload of the persons in charge. As a second important observation, the executive controllers (with a taskload mean of 190.6 min) are always more occupied than the planner controllers (146.6 min). Moreover both plots (executive and planner controllers' taskload) have a high correlation, showing clearly which

Table 2
Sectors of the SW FAB modeled.

Spanish		Portuguese	
Number	Name	Number	Name
1	GCCCOCE	7	LPPCCEU
2	GCCCRE2	9	LPPCWEST
3	GCCCRW4	10	LPPCMAD
4	LECMASL	11	LPPCNOL
5	LECMASU	12	LPPCNOU
6	LECMSAN	13	LPPCSOUTH
		14	LPPOALL

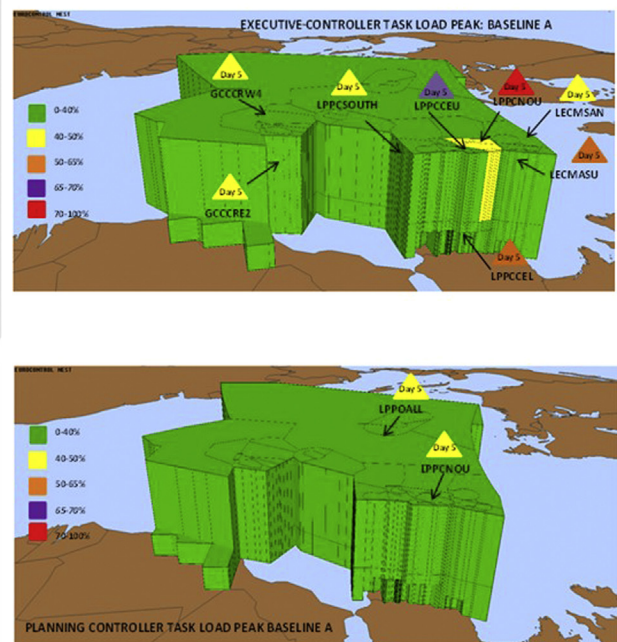
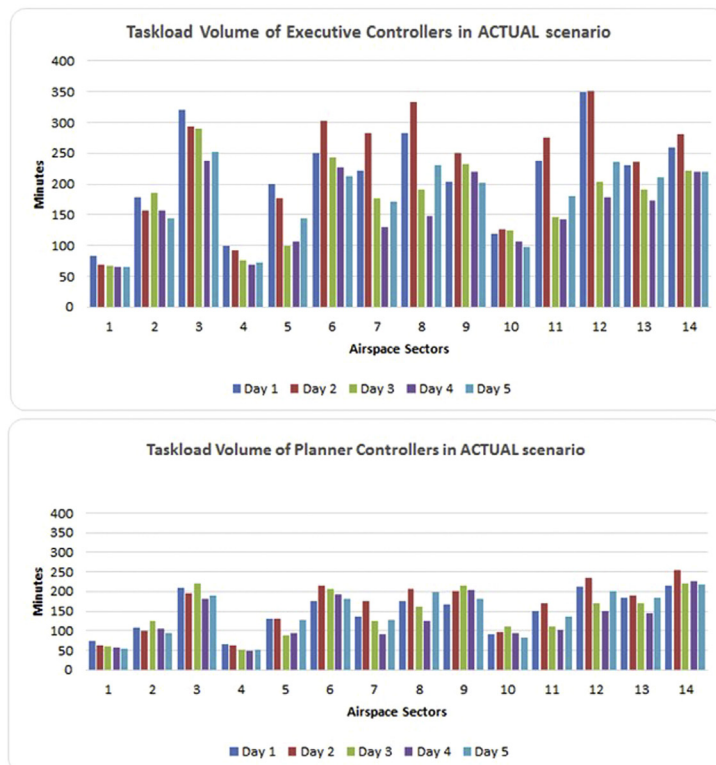


Fig. 6. Controllers' taskload for the ACTUAL scenario.

taskload peaks of Phase I and Phase II (not shown) we obtained a very 'green' map with minor peaks above 40% for Day 4, which were not significant. In Phase III the taskload congestion gets a little more visible, but still there is any situation of overload given for this amount of traffic.

To better test the possible implications of the SW FAB in the controllers' taskload we have calculated the same metrics for the FUTURE traffic scenario. Fig. 8 shows the results. When comparing the taskload metrics of the ACTUAL and the FUTURE scenarios we obtain a similar profile in the volume taskload, but significant differences in the peak taskload percent values. The volume taskload has a slight tendency to increase in the FUTURE, but still some sectors (ie. Sectors 2, 12 or 13) show even less taskload volume. This feature probably relates to the methodology used for the forecast of the traffic, promoting some routes in front of others. In the taskload volume plot we can also observe how free route provides important benefits, in terms of saved minutes of work, to the future increase of traffic.

In Fig. 7 we show the taskload metrics of the 3 phases of the ACTUAL scenario. First the taskload volume of the executive controllers for each phase are given. Then the peaks of the executive controllers' taskload are given only for the 3rd phase. The controllers' volume taskload plot shows that the highest values in the same three sectors for all 3 phases: GCCCRW4, LPPCEU and LPPCNOU with values very similar to the ACTUAL scenario. The highest volume taskload is 283 min (the GCCCRW4 sector in the Canary Islands). In general the taskload volume tends to decrease with the implantation of the free route phases. The only exceptions (sectors 1 and 11) are sectors with low traffic which may hold new flights if they use free routing, better balancing the taskload. For the

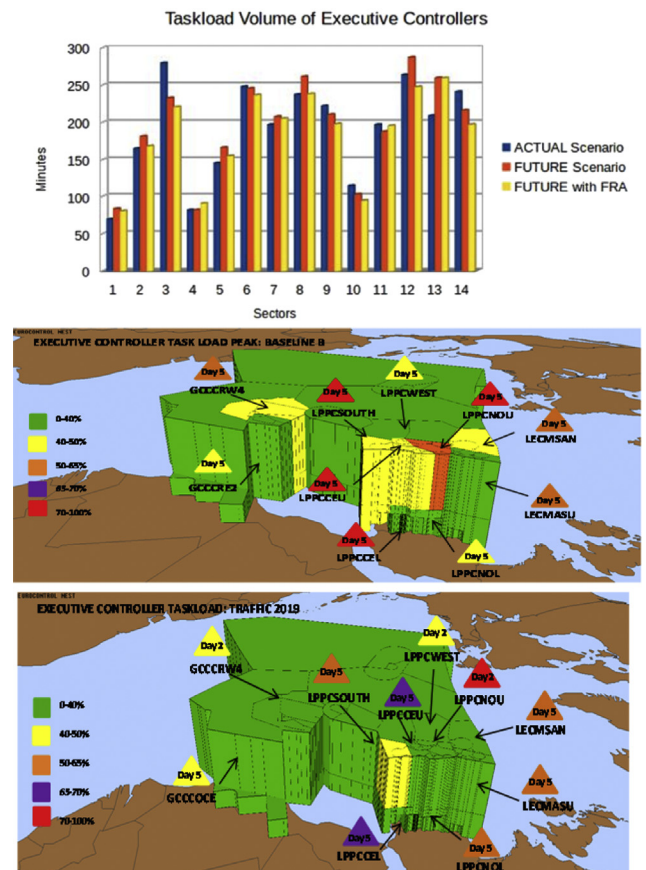


Fig. 8. Executive Controllers' Taskload (volume and peak) for the FUTURE scenario without and with FRA.

number of green colored sectors gets back to the original situation (13 sectors), and the number of overloaded sectors (red peaks icons) reduces to only one (sector LPPCNOU) with a value of 71.9% during some hour of Day 2.

The general evaluation of the metrics related to the controllers' taskload indicates that the implementation of free route in the SW FAB will not increment controllers' volume taskload or controllers' taskload peak. Moreover, with the expected growth of traffic of the future the results evidence the benefits of the free route to better deal with it.

6.3. Potential separation losses

The potential aircraft separation losses comparing the three SW FAB implementation phases and for the 5 traffic days of the ACTUAL traffic scenario are depicted Fig. 9. The number of potential separation losses per day are close to 400. Taking into account that these are for the whole extension of the SW FAB, this value can be considered safe and actually it is manageable by controllers. The differences observed when applying free route is that in general the number of potential separation losses decreases as the extension of the area of the free route phase increases. The only exceptions are for days 1 and 2, which have to wait until the implementation of Phase III to observe some benefits. This relation is probably due to the dispersion of the traffic samples over the airspace when applying free route, instead of the traditional airspace, where aircraft are accumulated in the airways producing more potential separation losses.

The number of potential separation losses in the FUTURE scenario is shown in Fig. 10. All 5 days show an increase of potential separation losses, directly related to the traffic increase. The average number of potential conflicts raises to a mean of 500 every day, with a significant increase for Day 2 (from 534 to 714). But when applying free route to the FUTURE traffic the metrics stay in a middle term between the ACTUAL and the FUTURE values. The worst case is again for Day 2 with 636 potential separation losses, still not very high for the large area been studied. Moreover most of the days the values are close or below the average of 400 and are considered manageable by controllers.

We can affirm that the free route airspace shows benefits for both stakeholders studied (airspace users and ANSPs), for current traffic but also when considering 2019 forecast traffic with significant 15% of increment.

7. Conclusions

State boundaries are a limitation for the operational improvements proposed in the SESAR programme for the modernization of the Single European Sky. The Functional Airspace Block is the

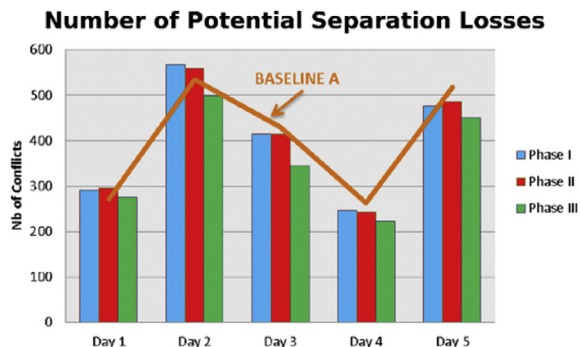


Fig. 9. Potential separation losses for the 3 phases of the ACTUAL scenario.

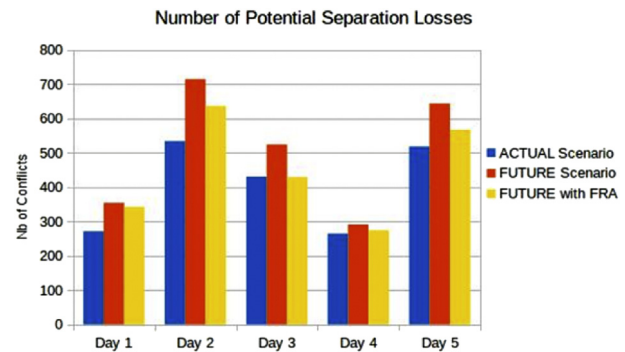


Fig. 10. Potential separation losses for the FUTURE scenario.

organizational concept of SESAR that aims at the elimination of this limitation. The SW FAB is the Functional Airspace Block created with the airspaces of Portugal and Spain which was pioneer on the introduction of free route operations in Europe. Development plans are set to offer in 2020 the longest FRA, especially useful for those oceanic flights on the northern–southern corridor. This traffic, currently around 1500–2000 flights a day, will benefit basically in saving flight distance.

In this paper we have presented the benefits of each of the three phases, planned according to the SW FAB Operational Task Force. The results shown that the three phases approach is correct, starting with small and ending with big, and obtaining more benefits (economical, operational and environmental) after each step. This approach allows contrasting the expected benefits with the actual ones before taking the next phase. The current situation is very close to Phase I, except that the FRA is still divided by national borders. For Phase III we obtain saving flight distances of 2–3% with represented savings also in a large number of fuel and emission tons and around 100,000 € a day for the airlines.

Moreover, we have obtained measures to evaluate the impact of the FRA in controllers' taskload and aircraft separation losses. Our simulation results show that not only airlines obtain benefits, but also taskload and conflicts measures respond in positive to the FRA routes. Even in the case of incrementing the traffic forecast, the positive tendency remains. The reason is the simplicity of the free routes, crossing the airspace with direct paths, avoiding unnecessary merging points and expanding the traffic all across the airspace. Nevertheless this traffic expansion does not follow any ordered pattern and might have a limit for high density traffic. For such a future, the FRA will be also complemented by other ATM global performance improvements, such as the 4D trajectory or the collaborative decision making. Putting all these technological and operational elements together, and with a unified calendar, is the big challenge of SESAR and NextGen programmes.

Acknowledgment

The authors would like to thank IFACATA and APCTA, the controllers association of Portugal and Spain, for their support in the resolving the questions raised during this research.

References

- Administration de la Navigation Aerienne de Luxembourg, August, 2008, Belgo-control, DFS, DSNA, LVNL, eurocontrol MUAC and Skyguide. FABEC Feasibility Study Report.
- Baumgartner, Marc, Finger, Matthias, 2014. The Single European Sky gridlock: a difficult 10 year reform process. *J. Air Transp. Manag.* 31, 289–301.
- Button, Kenneth, Neiva, Rui, 2013. Single European Sky and the functional airspace blocks: will they improve economic efficiency? *J. Air Transp. Manag.* 33, 73–80.
- Eurocontrol, 2013–2014. NEST User Manual, Version 1.3.

- Eurocontrol, Functional Airspace Blocks (online), retrieved by <https://www.eurocontrol.int/dossiers/fabs>. Last visited 6-Ago-2015.
- Eurocontrol, February, 2011. Fact Sheet “The Single European Sky”.
- Eurocontrol, February, 2011. At the Heart of a High-performance Cross-border Airspace.
- European Commission, Commission Regulation EU No 677/2011 Annex 1. European Route Network Design Function and European Route Network Improvement Plann (ERNIP).
- European Commission, Single European Sky. (online) retrieved from: http://ec.europa.eu/transport/modes/air/single_european_sky/index_en.htm. Last visited 6-Ago-2015.
- Gaydos, T., Liao, B., Smith, E., Wang, L., 2013. Analysis of conflict detection performance for trajectory-based descent operations. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- ICAO, 2008. Manual on Global Performance of the Air Navigation System. ICAO. Doc 9883, AN/468.
- Idris, H., Shen, N., 2013. Estimating airspace capacity based on risk mitigation metrics. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Knorr, D., Chen, X., Rose, M., Guldin, J., Enaud, P., Hegendoerfer, H., 2011. Estimating ATM efficiency pools in the descent phase of flight. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin.
- Kraus, J., December, 2011. Free route airspace (fra) in europe, pp. 3–7.
- Lee, P., Brasil, C., Homola, J., Kessel, A., Lee, H., Mainini, M., Prevot, T., 2011. Benefits and feasibility of the flexible airspace management concept: a human-in-the-loop evaluation of roles, procedures, and tools. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin.
- McNally, D., et al., 2013. Operational evaluation of dynamic weather routes at american airlines. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Mihetec, T., Steiner, S., Jakšić, Z., 2012. Analysis of Expected ATM Processes Changes in Central Europe, pp. 4–12.
- Portuguese and Spanish Directorate of Civil Aviation, June 2012. Southwest Fab Compliance Summary Document.
- Pozzi, S., Valbonesi, C., Beato, V., Volpini, R., Giustizieri, F., Lieutaud, F., Licu, A., 2011. Safety monitoring in the age of big data. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), Berlin.
- Eurocontrol, May, 2005. Final Report “To Support the Establishment of Functional Airspace Blocks (Fabs)”.
- Ryerson, M., Hansen, M., Bonn, J., 2011. Fuel consumption and operational performance. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin.
- Skybrary, Functional Airspace Block, (online) retrieved by http://www.skybrary.aero/index.php/Functional_Airspace_Block_%28FAB%29. Last visited 6-Ago-2015.
- Skybrary image (online), File: European_FAB retrieved by <http://www.skybrary.aero/index.php/>. Last visited 6-Ago-2015.
- Southwest FAB (website), retrieved by: <http://www.swfab.eu/home>. Last visited 6-Ago-2015.
- SW FAB Operational Task Force, June, 2012a. Airspace operational requirements report. Annex I. 61–83.
- SW FAB Operational Task Force, June 2012b. Sw fab airspace organisation and classification report. Annex O, 8–13, 65–68.
- SW FAB, Jun 2015. Operational Board. Operational Board Common Plan 2015–2019. http://www.swfab.eu/usersfiles/media/upload/150608_SW_FAB_OB_Common_Plan_15_19_v1.0.pdf. Last visited 6-Ago-2015.
- Timar, S., Hunter, G., Post, J., 2013. Assessing the benefits of NextGen performance based navigation (PBN). In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Tobaruela, G., Majumdar, A., Ochieng, W., Schuster, W., Hendrickx, P., 2013. Enhancing cost-efficiency and reducing capacity shortages: strategic planning and dynamic shift management. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Vaze, V., Barnhart, C., 2011. A multi-stakeholder evaluation of strategic slot allocation schemes under airline frequency competition. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin.
- Vogel, M., Schelbert, K., Fricke, H., Kistan, T., 2013. Analysis of airspace complexity factors' capability to predict workload and safety levels in the TMA. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Welch, J., Cho, J., Underhill, N., DeLaura, R., 2013. Sector workload model for benefits analysis and convective weather capacity prediction. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Wilmer, Cutler, Pickering, May 2001. Study of the European Commission on the Regulation of Airspace Management and Design.
- Wojcik, L., Mondoloni, S., Agbolosu-Amison, S., Wang, P., 2013. Flexibility metrics and their application to departure queue management. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Yifei, Z., De, Z., Rentian, Y., Hongyong, W., 2011. Method to analyse air traffic situation based on air traffic complexity map. In: 9th USA/Europe Air Traffic Management Research and Development Seminar (ATMf2011), Berlin.
- Zanin, M., 2013. Synchronization likelihood in aircraft trajectories. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.
- Zou, B., Elke, M., Hansen, M., 2013. Evaluating air carrier fuel efficiency in the U.S. airline industry. In: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago.